Single lens dual-aperture 3D imaging and the color remapping

Sam Y. Bae[1,2], Ronald Korniski[1], Allen Ream[3], Eric Fritz[4], Michael Shearn[1]

[1]Jet Propulsion Laboratory, California Institute of Technology
[2]University of California at Los Angeles, Los Angeles, California
[3]Montana State University, Bozeman, Montana
[4]University of Nebraska, Lincoln, Nebraska

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Outline

- Advantages in single lens dual-aperture 3D imaging
- Switching viewpoints through complementary bandpass Filters
- Problems in color mismatching
- Mitigation through color remapping
- 3-mm lens dual-aperture 3D camera

Motivation

SBI_vid1.mp4

	Open Surgery	Minimally Invasive Surgery
Surgical Opening	Large – Segment of skull	Small – Keyhole opening (endoscope ***4 mm*** O.D.)
Patient recovery	Lengthy – weeks	Short – a few days
Visual feedbacks	Strong – Full binocular vision, auditory, and haptic sensory	Weak – Dependence on 2D endoscope and remote tools with limited feedback

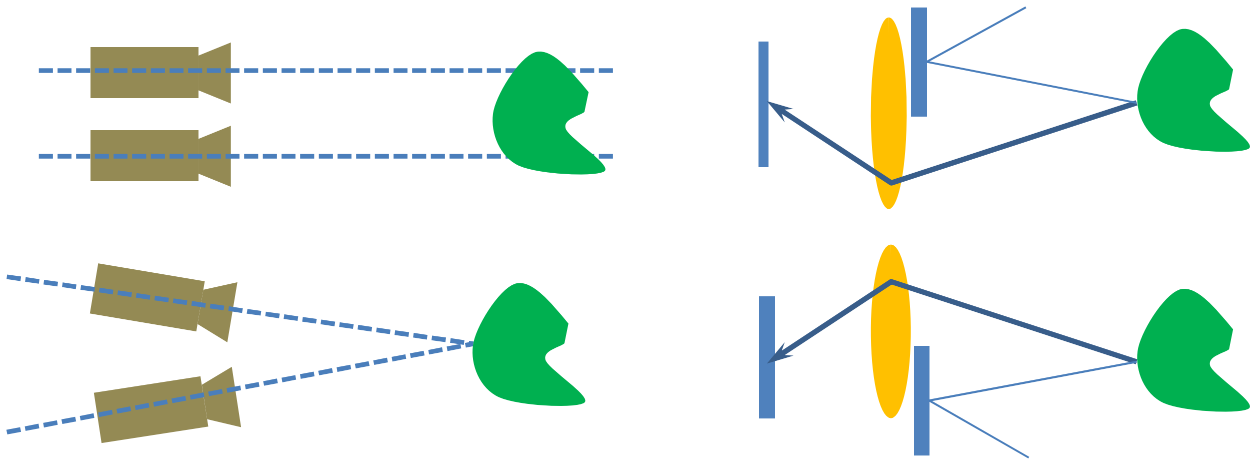
Objectives

- Build a 3D camera that:
  - Provides high definition, real-time, binocular (left- and right-viewpoint), images
  - Has dimensions no bigger than 4-mm in diameter.

- Examples close to the dimensions:

  Distal camera borescopes and endoscopes

Comparisons



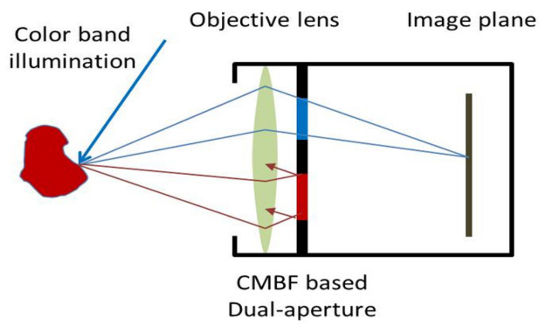
Two-camera 3D	Dual-aperture 3D
Two sets of objective lenses	Single objective lens (Simpler fabrication)
Two focal planes	One focal plane (High definition at the FPA)
Parallel viewpoints	**Natural vergence**

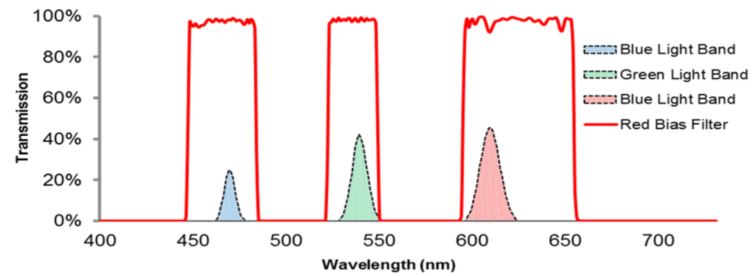
Past work to open half-apertı

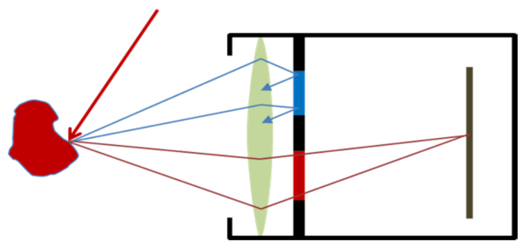
Mechanisms	Pros	Cons
Mechanical shutter	Complete open/block	Bulk, not instantaneous
Liquid crystal block	Fast switching	Incomplete open/block
Orthogonal polarizer pair	Passive	Light randomization
Complementary filter pair	Passive	Monochromatic images

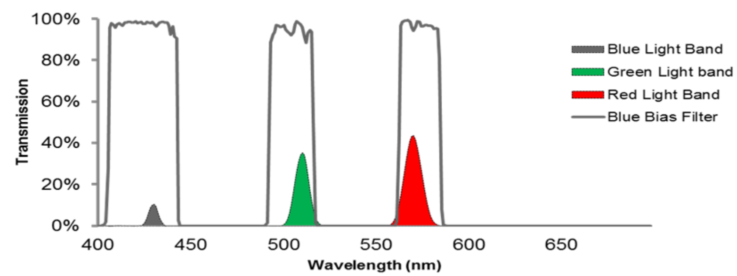
- Some of these require an extra space for the installation
- Some still have a problem with crosstalk between two channels

Complementary Multiband Bandpass Filters









Past work	Proposed work
Single band bandpass filters	Multi-band bandpass filters
2 spectral light source	6 spectral light sources
Single band spectral imge	RGB color expression

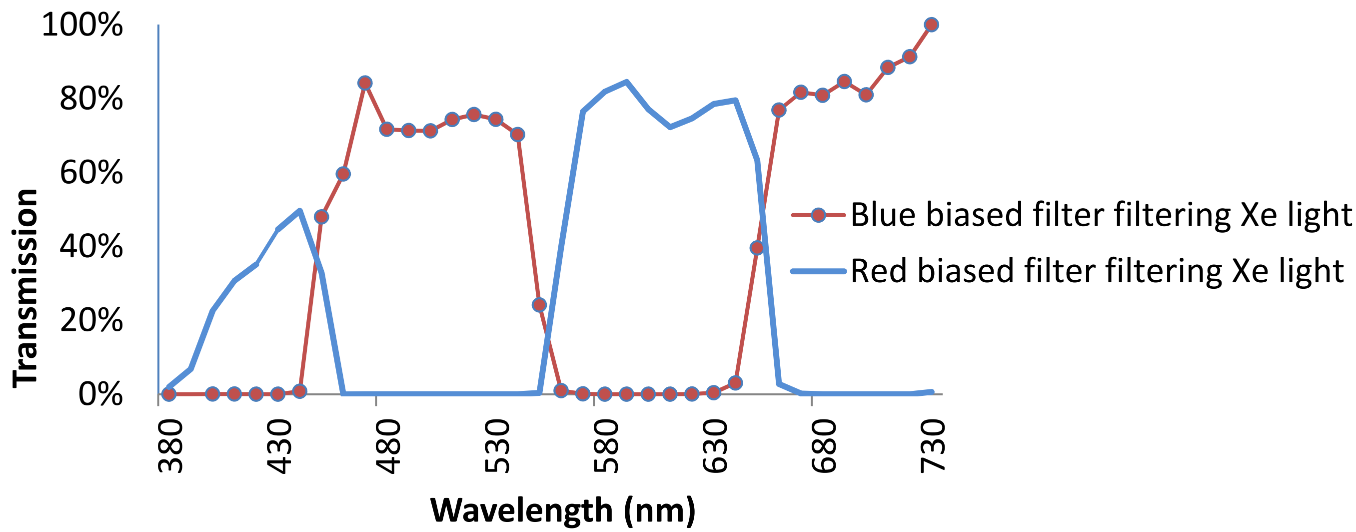
Problems

- Color rivalry (1-3)
  - Def.: two different colors competing in our brain when each presented to the eye.
  - The missing spectral bands creates the color difference between the two binocular images

(1) Hovis, JK, 1989, (2) Jung, YJ, 2011, (3) Ikeda, M., 1979

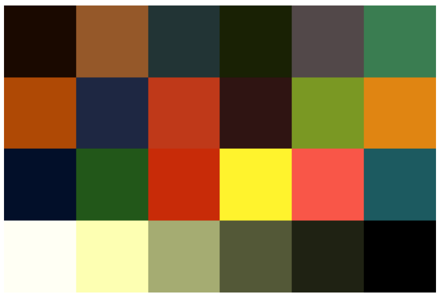
Mitigations

- Use bandpass containing more passbands
- Remap the colors, using Image processing

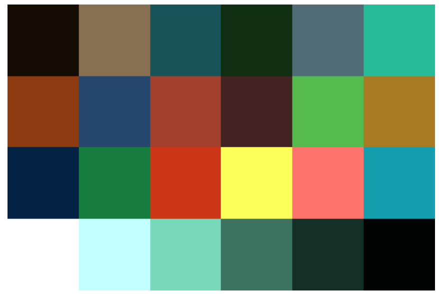


Spectral transmission of the dual-band bandbass filters under Xe lamp

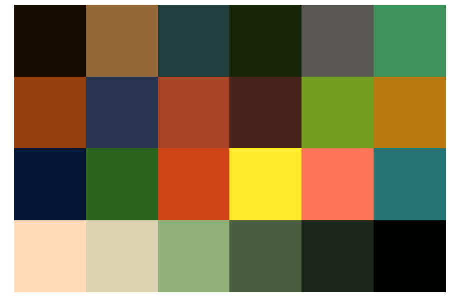
After remapping to look without the filters



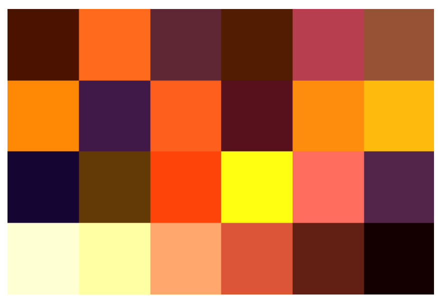
Without the filters, under Xe lamp



Raw image through blue bias filter



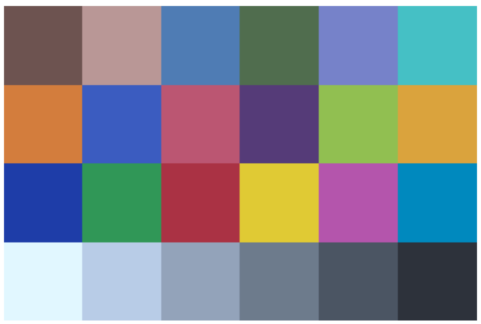
Remapped



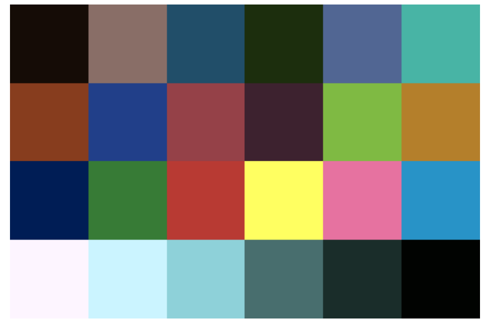
Raw image through red biased filter

Remapped

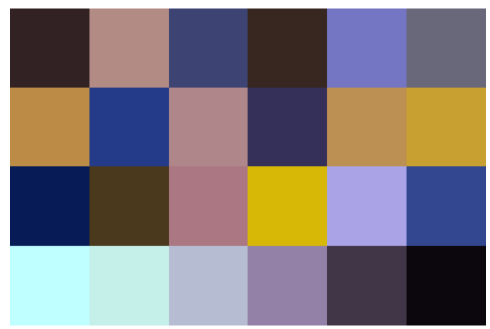
Remapped to look under daylight



Simulated image under daylight



Remapped blue biased image



Remapped red biased image

Dual-band results

	ΔE Lab raw	ΔE remap to D65	ΔE remap to Xe
Color diff.	46±25	25±14	23±14

Simulation results

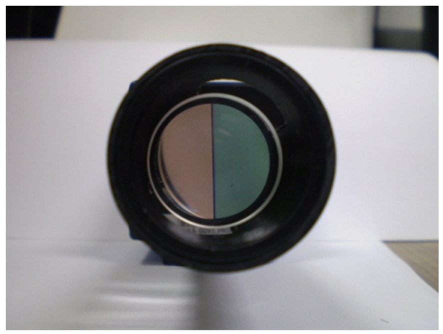
Complementary filter pairs	ΔE raw	ΔE of remapped values
Dual-band	82	48
Triple-band	163	43
Quadruple-band	57	19

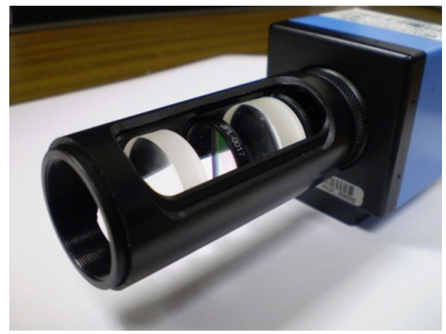
More the passbands that each filter has, smaller the color difference between the two channels

First generation CMBF 3D system

25-mm lens monochromatic camera, half-moon shape CMBFs, 6 multispectral images combined to produce a 3D

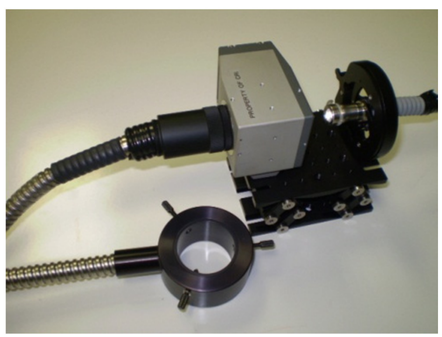
Half-moon shape CMBF

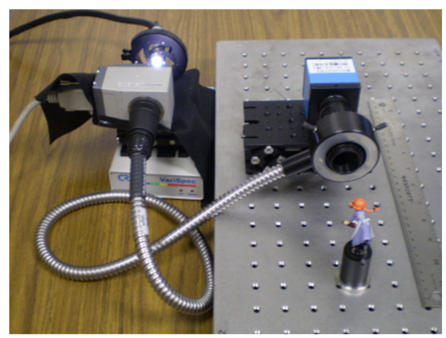




Lens system, two achromats + CMBF

A ring light connected to a tunable filter

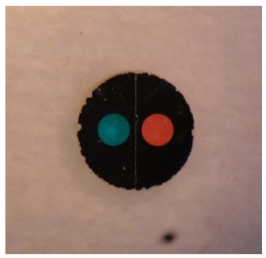


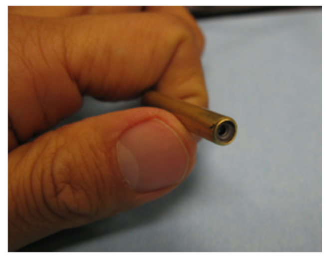


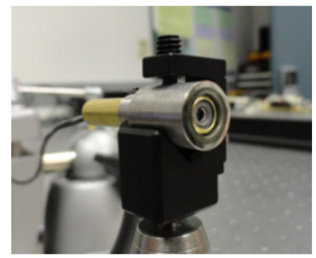
Overall system

Current prototype

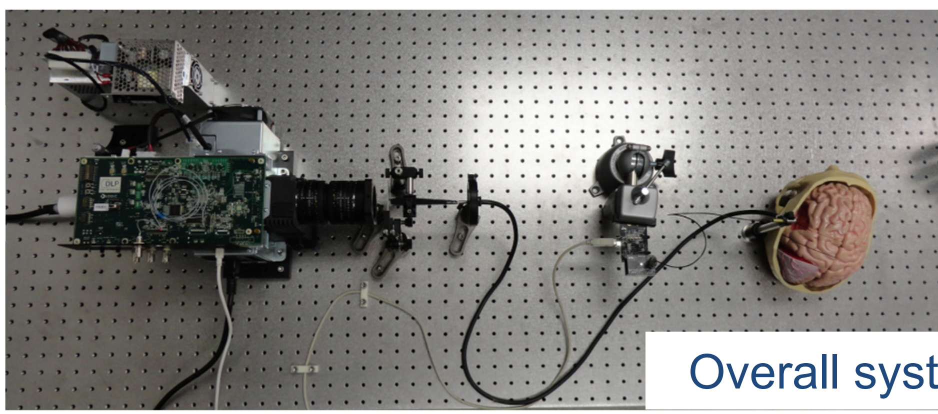
3-mm lens color camera, 9.35-mm overall Dia., custom fabricated CMBF, 2 multispectral images combined to produce 3D


Fabricated dual-aperture


3-mm lens


Ring light integrated

Illumination system


Overall system

Summary

- The dual-aperture has advantage in providing natural vergence and miniaturization
- Complementary bandpass filters (CBF) were used for opening the dual-aperture alternately
- The CBF results in producing unwanted color rivalry
- This was mitigated through using a simple remapping
- The dual-aperture concept was applied to building a 3D camera with 3-mm lens elements along with the remapping

Acknowledgement

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- I'd like to thank Professor Harold Monbouquette for his guidance in my PhD pursuit with this project

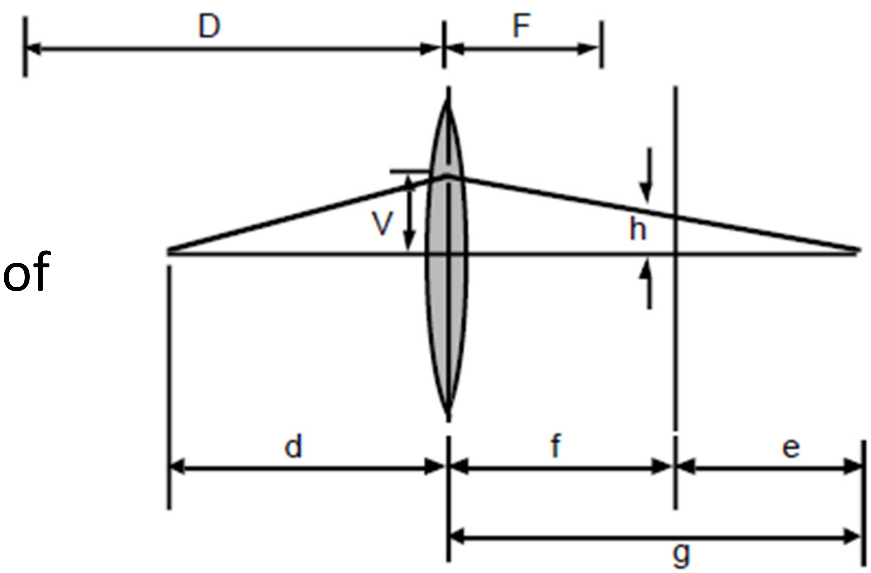
Back up slides

Dual-aperture Concept

- Disparity created by apertures offset from the optical axis:

$$\frac{1}{d} = \frac{h}{v}\left(\frac{1}{F} - \frac{1}{D}\right) + \frac{1}{D}\ ^{*}$$

Where *F* & *D and d* & *g* are pairs of conjugate planes

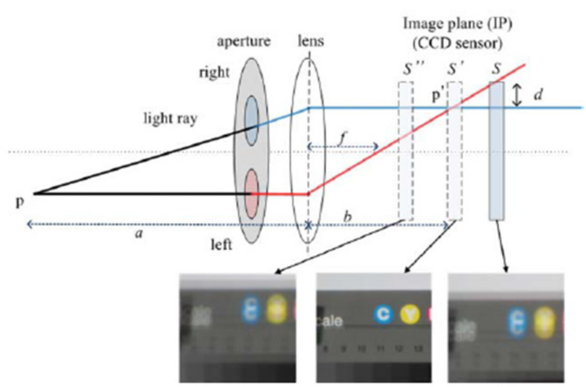


- Needs a mechanism to open/close half-apertures

*Adelson EH and Wang JYA, 1992

Past work using the color filters

- Amari used Red/green dual aperture and white light to estimate depths (1)
- Koh used Red/blue dual aperture and white light (2)
- Chen used RGB tri-aperture and white light (3)
- Bando used RGB tri-aperture and white light (4)

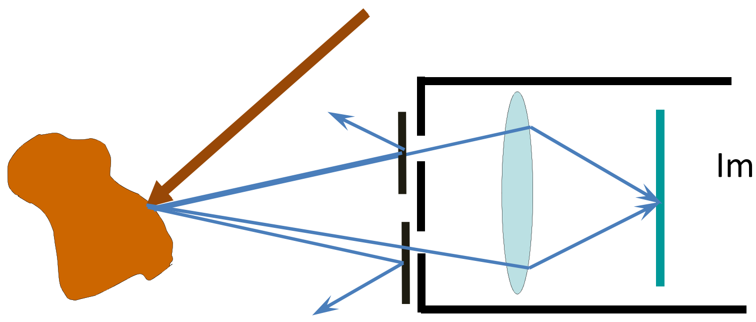


A pair of complementary single-band bandpass filters placed to create two optical paths


R, G, B bandpass filters placed to create three different optical paths

(1) Amari, Y. and Adelson, EH, 1992, (2) Chen, Y. et al, 2009, (3) Koh, K., 2011, (4) Bando, Y., 2008

Dual-aperture 3D camera



Open halves of the aperture one at a time

- Two viewpoints are created in a single objective lens camera
  - Uses a single image plane. High definition.
  - Built-in vergence when focused. Natural binocular vision.

	ΔE Lab raw	ΔE remap to D65	ΔE remap to Xe
Xe and D65	37±14	23±9	
Blue and Dest.	29±12	20±8	18±11
Red and Dest.	53±18	24±14	25±13
Color diff.	46±25	25±14	23±14